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Acute and Chronic Toxicity of Base Oil and Cuttings from Three Wells Drilled in the Beaufort Sea

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ABSTRACT

This study was conducted to evaluate the acute and chronic toxicity of drilling fluids, base oils and oiled cuttings used during the drilling of exploratory wells in the southern Beaufort Sea in 1983. Testing was conducted at the Environment Canada laboratory in St John's Newfoundland, during 1985/86.

The testing included a long-term (32-day) exposure of an invertebrate species to pre-determined concentrations of oiled cuttings and sand in seawater and 96 h and 192 h exposures of fish to the 100% water-soluble fraction of the base oils in freshwater. The cuttings/sand mixtures were prepared on a volume basis and simulated exposures at increasing distance from the rig discharge. The proportion of cuttings to sand ranged from 10% cuttings/90% sand to 90% cuttings/10% sand. The mixtures were spread evenly on the bottom of the exposure tanks to a depth of 3·5 cm and were overlayed with 20 cm of continuously replaced saltwater at a flow rate of 0·5–3 litre/min. The test species (Echinarachnius parma) *was distributed evenly over the sediment surface.*

The cuttings/sand mixtures were toxic to the invertebrate test organisms at concentrations of 10% cuttings by volume. Some sub-lethal effects were recorded (e.g. reduced burrowing and movement).

The 100% water-soluble fraction of base oils and oil released from cuttings were prepared according to the EPS (1985) protocol (Laboratory Procedure for Determining the Acute Lethality of a Water Soluble Fraction of Mineral Oil to Rainbow Trout. Environment Canada, EPS, Atlantic Region, Dartmouth, N.S.). The validity of the protocol was also examined by varying

the mixing, settling and exposure times. Screening of base oils alone using the water-soluble fraction technique was not indicative of any toxic effects of oily cuttings on invertebrates.

1. INTRODUCTION

The acute toxicity of diesel oil associated with discharged cuttings became a major concern in the North Sea in the late 1970s. A different base oil, with a lower aromatic hydrocarbon content and lower acute lethality, began to be used to replace diesel oil in drilling muds in the early 1980s. Hinds *et al.* (1983) demonstrated that when fish and marine invertebrates were exposed to water-soluble fractions (WSF) of low toxicity oils the 96 h LC_{50}s were typically greater than 10 000 ppm as compared to LC_{50}s of less than 2000 ppm for diesel oil. Studies conducted by Barchard & Doe (1984), Doe *et al.* (1984) and Hutcheson *et al.* (1984) on cuttings, base oils and drilling muds, respectively, collected from the Alma F-67 well drilled near Sable Island, indicated that discharged cuttings with their retained oil were toxic to selected marine invertebrates.

The use of oil-based drilling mud in Canadian offshore areas has been approved on a well-by-well basis, on the basis of guidelines for this drilling method issued by the Canada Oil and Gas Lands Administration (1986). Permits have occasionally included requirements for monitoring as well as specific conditions on the disposal of oiled cuttings. Some of the monitoring results are presented in other papers in these conference proceedings. The drilling conditions afforded an opportunity to collect large samples of oiled cuttings, base oils and mud for testing purposes. During the period of 1982–1984 Environment Canada subjected a number of oil-based mud formulations and components to toxicity testing (Doe *et al.*, 1984; Barchard *et al.*, 1985). The work presented in this paper continued that program and deals with cuttings from three wells drilled in the southern Beaufort Sea—Nipterk L-19A, Adgo G-24 and Minuk I-53.

The studies were designed to evaluate the acute and chronic effects of selected concentrations of cuttings in sediments on invertebrates, and the acute lethality of the WSF of base oils and oil released from cuttings on rainbow trout (*Salmo gairdneri*). The applicability of the protocol for preparation of the WSF and the acute toxicity evaluations were examined in relation to the effects recorded on invertebrates.

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2. METHODS AND MATERIALS

2.1. Sample Collection

The oily cuttings were collected from three wells, that is, from storage of undischarged cuttings at the Nipterk L-19A and Adgo G-24 sites and directly from the shale shakers at the Minuk I-53 site. The cuttings were sealed in plastic containers and shipped from the Arctic to St John's, Newfoundland within 10 days, where they were stored at $4 \pm 0{\cdot}2°C$ until used in testing. Conoco Vista ODC base oil containing 2% ESSO DMO-75 base oil was also collected at the Minuk I-53 site. Shell Canada provided a base oil from stock, Shell Sol DMS Mineral Oil.

2.2. Water-soluble Fraction—Acute Tests

Water-soluble fractions of the base oils and oil released from cuttings were prepared according to the EPS (1985) protocol. A diesel WSF was prepared for comparative purposes. Additional WSFs were prepared based on a modified procedure of the Environmental Protection Service (EPS, 1985) protocol. The WSFs were prepared from each sample by using different combinations of mixing time (20, 25 and 29 h), settling time (2, 4 and 6 h), and sample-to-water ratio (0·5:9·5, 1:9, 1·5:8·5 and 2:8) (Table 1). The acute toxicity of the WSF to rainbow trout was determined and the parameters resulting in the lowest LT_{50} (time to 50% mortality in fixed concentration) was used to prepare subsequent WSFs.

TABLE 1
Summary of the water soluble fraction (WSF) preparation regime

Mixing time (h)	*Settling time (h)*	*Ratio sample : water*
20	4	0·5:9·5
25	4	0·5:9·5
29	4	0·5:9·5
Time at which greatest toxic effect or oil/grease content was observed	2	0·5:9·5
	6	0·5:9·5
Time at which greatest toxic effect or oil/grease content was observed	Time at which greatest toxic effect or oil/grease content was observed	1:9
		1·5:9·5
		2:8

Toxicity tests using WSFs of base oils were conducted following a standard protocol for testing the toxicity of liquid effluents (EPS, 1982); the exposure period was 192 h instead of the prescribed 96 h. The test organism was laboratory-acclimated rainbow trout with a mean weight of 1·47 g. The test solutions were kept at 15 ± 1°C, and not aerated during the test. The test organisms were exposed to each of the WSFs and controls were maintained concurrently; dissolved oxygen and pH were determined at the start and finish of each test. The LT_{50} values were calculated according to the method of Litchfield (1949).

2.3. Chronic Tests

Chronic effects of cuttings were monitored by observing behaviour and mortality among laboratory-acclimated sand dollars (*Echinarachnius parma*) exposed to cuttings for 32 days. The methods used by Hutcheson *et al.* (1984) were followed.

The cuttings and sand were thoroughly mixed in the test tanks to simulate sea-floor conditions after a number of seasons when ice scour and wave action would result in mixing and redistribution of cuttings with local sediment. Each test tank had approximately 3·5 cm of the cuttings and No.1 silica sand covering the bottom (Table 2). The control tanks contained 3·5 cm of washed No.1 silica sand. Ambient seawater (average salinity 27 ppt) flowed continuously into the tanks at a replacement rate of 0·5–3 litre/min, to maintain a water depth of 20 cm over the cuttings. No aeration was supplied since replacement seawater was at the O_2 saturation level. Dissolved oxygen and pH was determined at the start and finish of each test (Table 3).

Five to ten sand dollars were evenly distributed over each of the tanks. The number of dead sand dollars was recorded every 2 days; death was defined as a lack of movement of tube feet when examined using a dissecting microscope. Dead individuals were removed. Observations of number of burrowed individuals and distance travelled were made daily. Test organisms were not fed during the test period.

2.4. Oil Analyses

The total oil and grease content of the WSF and sediment/cuttings mixtures was determined at the beginning and end of each test (Table 4). Analysis was performed by the partition gravimetric method (APHA/AWWA/WPCF, 1980) with freon extraction.

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TABLE 2
Chronic assay tank and test species information

Sample	*Depth*	*Proportion of cuttings/ sand (V/V)*	*Size of tank (cm)*	*Numbers of* E. parma
Phase 1				
Nipterk L-19A				
	800 m	100% cuttings on sand	44 × 100	5
	1900 m	100% cuttings on sand	44 × 100	5
	3100 m	100% cuttings	44 × 100	5
Control	NA	0/100	44 × 100	5
Phase 2				
Nipterk L-19A				
	NA	10/90	44 × 100	10
	NA	25/75	44 × 100	10
	NA	50/50	44 × 100	10
	NA	75/25	36 × 56	5
Control	NA	0/100	44 × 100	10
ADGO G-24				
	500 m	25/75	75 × 77	10
		50/50	75 × 77	10
	1100 m	25/75	75 × 77	10
		50/50	75 × 77	10
	3087 m	25/75	75 × 77	10
		50/50	75 × 77	10
Control	NA	0/100	75 × 77	10
Minuk I-53				
	2350 m	10/90	44 × 100	10
		25/75	44 × 100	10
		50/50	44 × 100	9
		75/25	44 × 100	10
		100% cuttings on sand	44 × 100	10
Control	NA	0/100	44 × 100	10

NA = not applicable.

TABLE 3
Summary of experimental conditions of chronic toxicity tests

Sample	Initial				Final			
	pH	DO[a]	Temp (°C)	Salinity (ppt)	pH	DO	Temp (°C)	Salinity (ppt)
Phase 1								
Nipterk L-19A								
800 m	8·0	8·5	12	NA	8·1	9·0	11	27
1 900 m	8·0	8·9	12	NA	8·1	10·2	11	27
3 100 m	8·0	8·5	13	28	8·0	10·3	9	28
Control	8·0	8·7	12	28	8·0	10·0	10	27
Phase 2								
Nipterk L-19A								
10/90	7·9	12·1	2	29	7·9	11·8	2	24
25/75	7·9	11·9	2	29	7·9	11·9	2	24
50/50	7·9	11·9	2	29	7·9	11·0	2	24
75/25	7·9	12·3	0	29	7·9	12·3	2	24
Control 0/100	7·9	12·2	2	29	7·9	12·2	2	24
ADGO G-24								
500 m 25/75	7·9	12·3	2	29	7·7	11·4	3	27
500 m 50/50	7·9	12·1	2	29	7·8	11·9	3	27
1 100 m 25/75	7·9	12·7	2	30	7·8	11·7	3	28
1 100 m 50/50	7·9	12·0	1	30	7·8	11·9	3	27
3 087 m 25/75	7·9	12·1	2	29	7·7	11·7	3	27
3 087 m 50/50	7·9	12·5	2	29	7·8	11·3	3	28
Control 0/100	7·9	12·2	2	29	7·9	12·1	3	28
Minuk I-53								
10/90	7·8	12·4	2	30	7·9	12·2	2	24
25/75	7·8	12·5	2	30	7·9	11·5	2	24
50/50	7·6	12·5	2	30	7·6	11·6	1	27
75/25	7·8	12·4	2	30	7·9	12·3	2	24
100% cuttings on sand	7·8	12·5	2	30	7·9	12·5	2	24
Control	7·9	12·2	2	29	7·9	11·9	2	27

[a] Dissolved oxygen content (ppm).
NA = not available.

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TABLE 4
Initial and final oil/grease contents of sediments of the chronic toxicity test tanks

Test tank	*Initial oil/grease content (g/100 g)*	*Final oil/grease content (g/100 g)*	*Aromatics content (g/100 g)*
Minuk I-53			
10/90	0·52	0·6	0·03
25/75	1·3	0·9	0·05
50/50	2·6	NA	NA
75/25	3·9	2·3	0·12
100% cuttings on sand	5·2	3·1	0·16
Sand beneath 100% cuttings	0	0	0
Nipterk L-19A			
10/90	2·4	2·4	0·64
25/75	6·0	5·2	1·40
50/50	12·0	9·8	2·63
75/25	18·0	11·9	3·19
ADGO G-24 500 m			
25/75	3·1	2·6	0·005
50/50	6·1	4·5	0·008
ADGO G-24 1 100 m			
25/75	3·2	7·5	0·015
50/50	6·4	6·7	0·013
ADGO G-24 3 087 m			
25/75	2·1	2·4	0·005
50/50	4·1	4·6	0·009

NA = not available.

3. RESULTS

3.1. Water-soluble Fraction—Acute Tests

The oil and grease content of the 96 h water-soluble fraction tests are presented in Table 5. None of the WSFs was acutely lethal to rainbow trout in 96 h tests. In 192 h tests, however, the WSF of oil released from Adgo G-24 cuttings was acutely lethal to all test organisms in 32–142 h. All other combinations of mixing and settling times were not acutely lethal (Table 5). It should be noted that the pH in the Adgo G-24 series was initially 8·6–9.8. This could account for the lethal response, although it had decreased to 6·1–6·5 by the end of 96 h.

TABLE 5
Summary of results of mixing regimes, LT_{50}s, oil/grease content, and total suspended solids content (fresh water tests)

Mixing time (h)	*Settling time (h)*	*Ratio (oil:water)*	*% Mortality at 192 h*	*LT_{50} (h)*	*Initial O/G (mg/litre)*	*TSS (JTU)*
Shell Sol DMS Mineral Oil						
20	4	0·5:9·5	0	>192	0·59	0
25	4	0·5:9·5	0	>192	0·55	0·88
29	4	0·5:9·5	0	>192	2·17	0·60
29	2	0·5:9·5	20	>192	1·06	0
29	6	0·5:9·5	0	>192	0·79	0
29	4	1:9	0	>192	0·50	0·32
29	4	1·5:8·5	0	>192	0·73	0
29	4	2:8	20	>192	0·83	0·55
Conoco Vista ODC-Rich Drilling Fluid (ADGO G-24)						
20	4	0·5:9·5	100	33·9	1·42	NA
25	4	0·5:9·5	100	33·9	1·59	0·42
29	4	0·5:9·5	100	53·0	0·46	0
25	2	0·5:9·5	100	49·1	0·97	1·56
25	6	0·5:9·5	80	63·0	0·33	0·51
25	4	1:9	80	141·9	2·38	0·07
Esso DMO75-Rich Drilling Fluid (Nipterk L-19A)						
20	4	0·5:9·5	0	>192	0·77	2·19
25	4	0·5:9·5	0	>192	0·83	0
29	4	0·5:9·5	0	>192	1·11	0
29	2	0·5:9·5	0	>192	2·70	1·08
29	6	0·5:9·5	0	>192	0·52	2·22

3.2. Chronic Tests

Exposure to the various cuttings/sand mixtures of Niptek L19-A and Adgo G-24 samples caused 100% mortality of sand dollars within 27 and 21 days, respectively (Figs 1 and 3). The Minuk mixtures, however, were not acutely lethal; average mortality was 16% after 32 days, with a range of 10–30% (Fig. 2).

There was no movement or burrowing activity of sand dollars in those tests where eventual 100% mortality occurred. In the Minuk I-53 series

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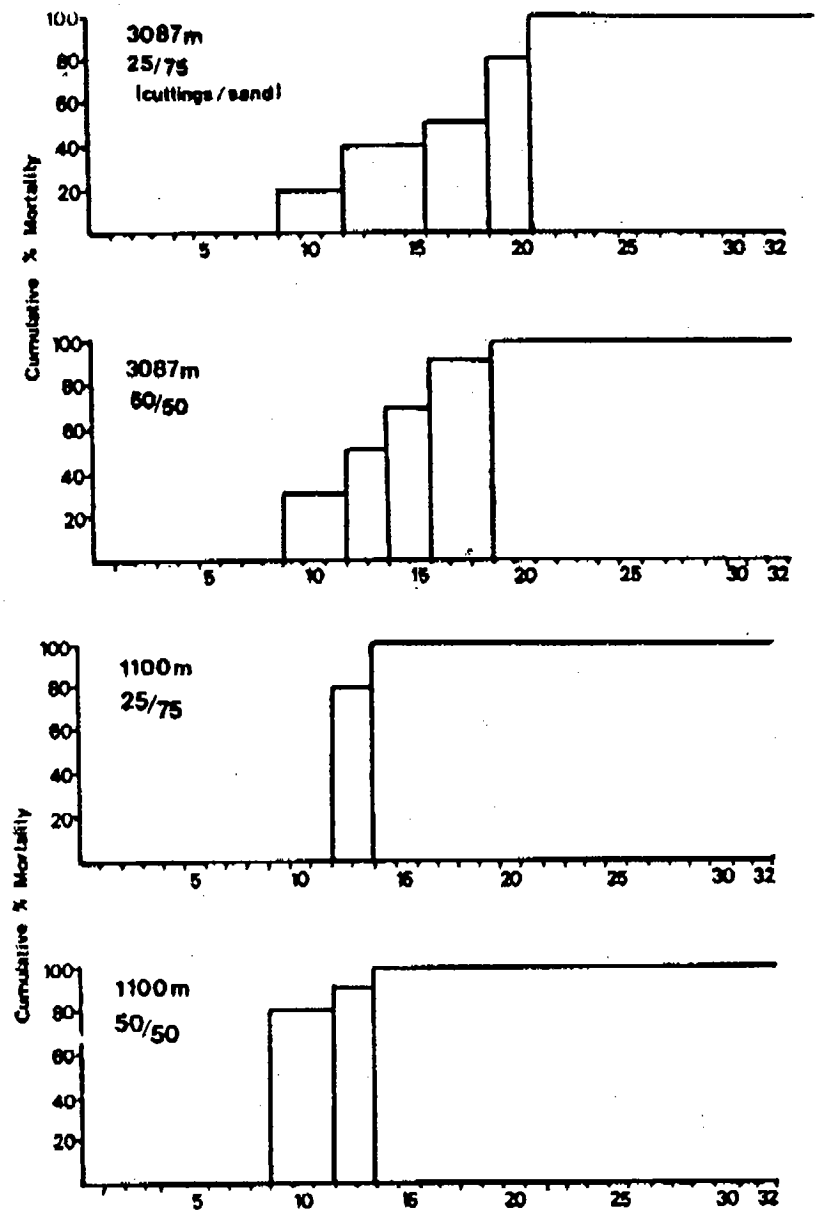

FIG. 1. Cumulative % mortality of *Echinarachnius parma* in ADGO G-24 assays.

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of tests, none of the sand dollars burrowed in the 100% cuttings layered on sand and distance travelled was negligible, although only 30% mortality was recorded. The number of burrowed individuals in the Minuk I-53 cuttings/sand mixtures 10/90, 25/75, 50/50 and 75/25 was significantly less than that recorded in controls (Mann–Whitney *U*-test), and movement along the surface was reduced for all but the 10/90 cuttings/sand mixture. Distance travelled in the 10/90 mixture was comparable to controls.

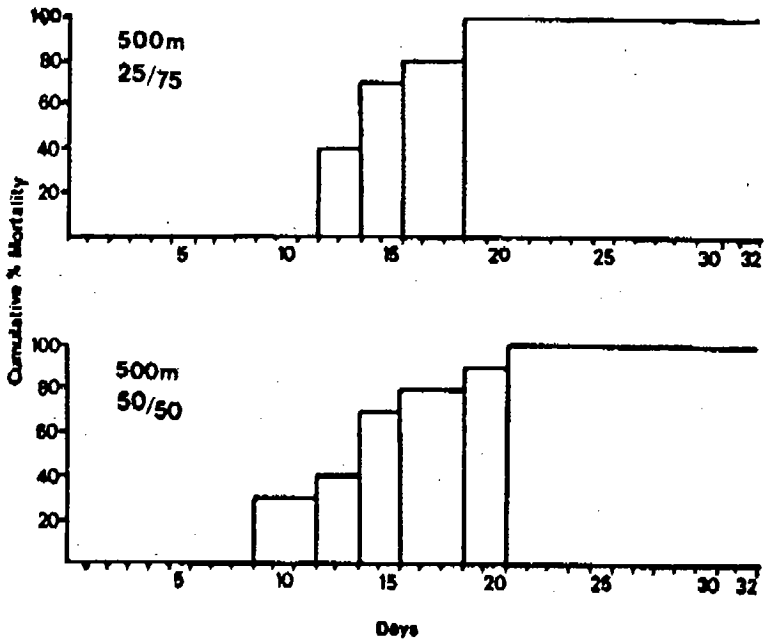

FIG. 1. —*contd.*

4. DISCUSSION

In 1986, the Canada Oil and Gas Lands Administration issued guidelines for the use of oil-base drilling mud (COGLA, 1986). These guidelines require that the base oil used be not acutely lethal to rainbow trout in 96 h LT_{50} tests of the 100% water-soluble fraction. The preparation of the water-soluble fraction for these tests was to follow the EPS (1985) protocol. This protocol was based on the work of Anderson *et al.* (1974) and required the stirring of a 1:9 oil:water ratio for 20 h, followed by 4 h of settling.

The work of Anderson *et al.* (1974) was based on crude oils and fuel oils, composed of different classes of hydrocarbons from the mineral oil used for today's 'low toxicity' oil-based muds. Diesel oil can contain approximately 20% mono- and di-aromatic hydrocarbons whereas the permitted mineral oils contain less than 5% of these compounds. Thoresen & Hinds (1983) attributed the toxicity of base oils to their mono- and di-aromatic hydrocarbon content. The aromatics are more soluble in water than the aliphatics which comprise the majority of the hydrocarbon content in mineral oils. The observed low toxicity in acute lethal tests of mineral oils may be in part due to low solubility and thus bio-availability of the aliphatics (Rice *et al.*, 1976).

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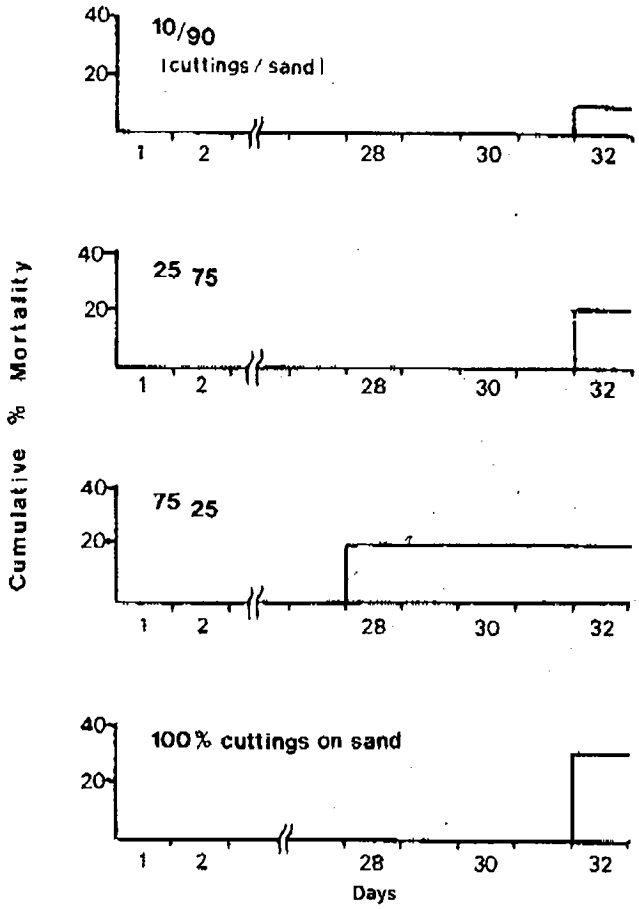

FIG. 2. Cumulative % mortality of *Echinarachnius parma* in Minuk I-53 assays. (NB: 0% mortality in 50:50)

The oil and grease content of the WSF of mineral oil and oil released from cuttings was less than 3 ppm, and no evidence exists to correlate toxicity with the concentration of oil and grease. It would appear that the present protocol for preparation of the WSF will result in a concentration of oil in water that is sufficient to measure the acute toxicity of the base oil, but not necessarily its effects after discharge as part of the cuttings.

The oiled cuttings from Nipterk L-19A and Adgo G-24 were toxic to *E. parma* within 26 days and 50% mortality occurred within 20 days. Hutcheson *et al.* (1984) recommended a 20-day exposure regime for the species tested; this appears to be a reasonable time period to determine chronic effects.

E. parma normally feeds as it moves over and through sediment.

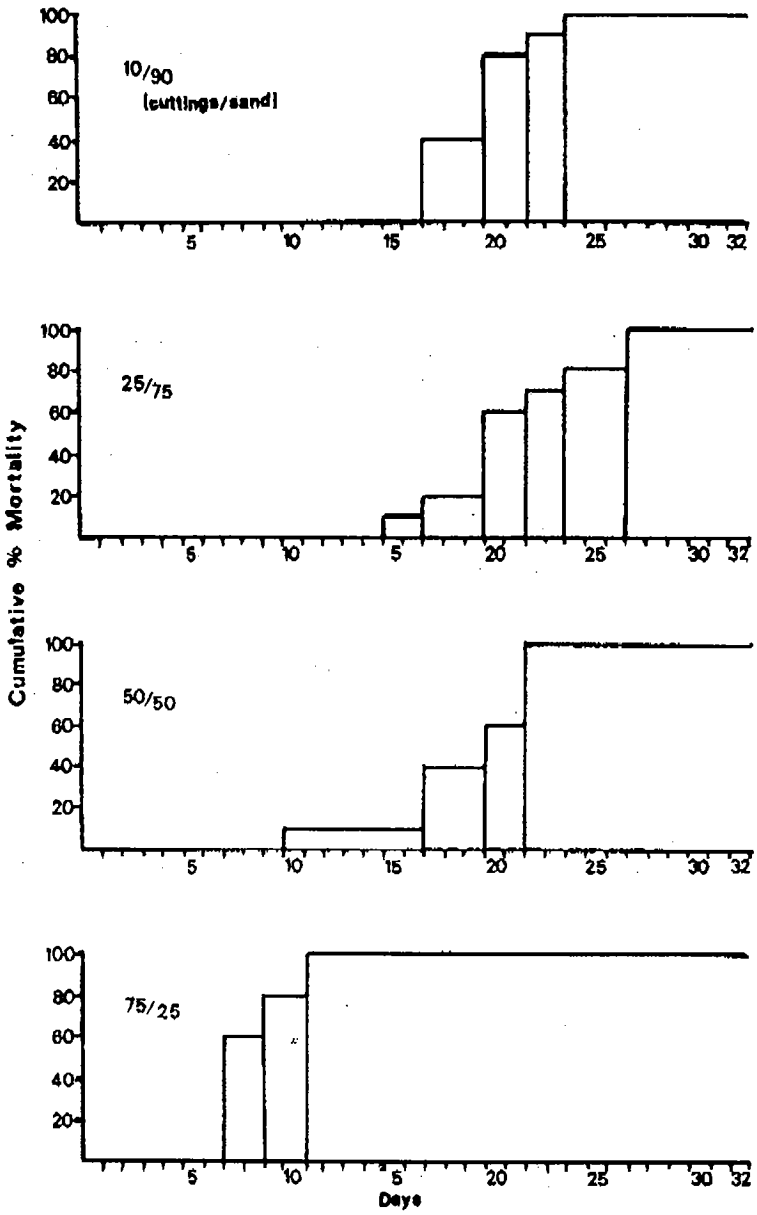

FIG. 3. Cumulative % mortality of *Echinarachnius parma* in Nipterk L-19A assays.

Reduced movement would affect food consumption and the ability of the animal to survive. It was not possible to determine if starvation was a contributing factor in those tests where 100% mortality occurred, but survival of individuals in the Minuk I-53 tests where burrowing was inhibited would seem to discount starvation. However, anoxic conditions due to biodegradation of the cuttings may have decreased oxygen

concentration at the sediment:water interface even though incoming sea water was at O_2 saturation. The presence of anoxic conditions in the top few millimetres of cuttings was noted by Gillam *et al.* (1986) in work conducted in the North Sea.

The results of our tests indicated that oily cuttings/sediment mixtures with as little as 10% oily cuttings although not necessarily acutely lethal could affect survival of benthic organisms. Since the chronic effects were not observed in all test regimes, the quality of oil on the cuttings, the chemical additives, and the rate of biodegradation of oil may be an influence on the potential for chronic toxicity.

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